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A 2-stage method for a field service routing problem with stochastic travel and service times

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ABSTRACT

In this paper, we consider a specific variant of the field service routing problem. It consists in determining vehicle routes in a single period to serve two types of customers: mandatory and optional. Mandatory customers have to be served within a specified time window whereas optional customers may be served (or not) within the planning horizon. For more realism, we assume that service as well as travel times are stochastic and also that there are multiple depots. The objective is to visit as many optional customers as possible while minimizing the total travel time. To tackle this problem, we propose a 2-stage solution method: the planning stage and the execution stage. We decompose the planning stage into two phases: the design of a skeleton of mandatory customers and the insertion of optional customers in this skeleton. In the execution stage, we proceed to a real-time modification of the planned routes to face stochastic travel and service times and to enable time windows to be respected.

1. Introduction

The field service routing problem consists, given a limited number of technicians, in determining a set of optimal technician routes to serve customer requests, while ensuring that each technician has the required skills for his tasks. The problem we are dealing with in this paper is a variant of the single-period field service routing problem without technician skills. In this variant, we suppose that all customers are known a priori and we distinguish between two types of customers: mandatory and optional customers. Optional customers have an associated time window corresponding to the time horizon and may be postponed at any time. Mandatory customers have an associated hard time window (they must be served within this time window). We associate to each technician a vehicle and we suppose that each vehicle has unlimited capacity, its own origin and destination depots and must return to this destination depot by the end of the period (hard time window). We consider that travel and service times for all customers (mandatory and optional) are stochastic. The objective is to visit as many optional customers as possible while minimizing the total travel time. This problem can also be seen as a variant of the vehicle routing problem with time windows (VRPTW). Indeed, the VRPTW consists in determining a set of optimal vehicle routes serving all customers to meet customer demands within specified time windows, each of these routes starting and ending at a given depot. The objective in the VRPTW is to minimize the total traveled distance and also, sometimes, the number of vehicles. Compared to this classical VRPTW, our variant present some differences as we consider multiple depots, uncapacitated vehicles, priority within customers as well as stochastic travel and service times. In the remainder of this paper, we will call this variant the Multi-Depot Vehicle Routing Problem with Time Windows, Stochastic Service and Travel Times and with priority (MDVRPTWSSTT with priority).

A generic application of the MDVRPTWSSTT with priority we consider is the design of routes for technicians for repair and maintenance operations. Mandatory customers are requiring repair operations whereas optional customers are requiring a service (control, maintenance, meter-reading…). In this application, as it is about service routing, vehicles are used only for carrying material and personnel. Thus we can suppose that the vehicle capacity is unlimited. Moreover, as vehicles do not carry goods, they can have their own origin and destination depots (typically technician homes). Last, as the service provided to the customer may be a repair operation, we understand the need to consider stochastic service times. The particular application that we are considering corresponds to a real problem coming from a leading international company in the area of domestic water provision and treatment. In this company, technicians have to perform maintenance operations (corresponding to optional customers) and repair operations (corresponding to mandatory customers). It is described in Tricoire et al. [1,2] and Binart et al. [3] as well as Bostel et al. [4]. In this paper, we consider uncertainties

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in both travel times between clients and duration of service at customers' premises. Uncertainties are indeed a major problem in a real application of this kind, especially to reach efficient solutions during the real-time execution stage. To the best of our knowledge, no previous work has been reported on the problem we just defined. Therefore, we will first focus on literature dealing with variants of the field service routing problem and then on literature dealing with the vehicle routing problem with time windows (VRPTW) with common characteristics to the MDVRPTWSSTT with priority.

Since a few decades, the problem of field service routing has arised in the literature with the development of the service industry. In 2002, Grötschel et al. [5] address a realtime variant of the field service routing problem and propose a column generation method with a dynamic pricing strategy. More recently, Kovacs et al. [6] propose an adaptive large neighborhood search for solving the field service routing problem with and without team building. Borenstein et al. [7] and Delage et al. [8] consider the field service routing problem with stochastic service times. Borenstein et al. [7] proceed in many steps: they first partition customers into different clusters, then assign technicians to them. To get a soft clustering, they make the tasks located at the boundary between areas belong to all adjacent areas. After this soft clustering, they define some rules to allocate tasks to technicians. Delage et al. [8] proposes a two-step method: he first establishes workload planning and then he deals with stochastic service times thanks to a dynamic programming approach. Last, Cortes et al. [9] and Souyris et al. [10] address the field service routing problem with stochastic service times and a priority within customers (corresponding to a target response time). Tricoire et al. [1,2] and Bostel et al. [4] have been interested in the deterministic multiple depot, multiperiod field service routing with priority within customers (MDVRPTW with priority), distinguishing mandatory and optional customers. For this problem, they propose a column generation-based method [11] as well as a memetic algorithm [12]. In 2006, Dugardin et al. [13] deals with the single-period field service routing problem with priority within customers, but he considers stochastic travel times. However, he does not take into account the stochasticity when building the route plan. Given a route plan, he defines simple rules to react to the different events which may occur. Even if the VRPTW has been addressed in many papers, few are those taking into account stochastic travel and/or service times. Ando et al. [14], Russell et al. [15], Jie [16], and Tas et al. [17] formulate the VRPTW with stochastic travel times as an integer program and seek to minimize the weighted sum of total traveled distance and penalties related to the violation of time windows. Moreover, Ando et al. [14] and Russell et al. [15] minimize the number of vehicles used. To solve this problem, Russell et al. [15] and Tas et al. [17] propose a tabu search based algorithm whereas Jie [16] present an evolutionary algorithm.

Some authors have been interested in the VRPTW with stochastic service times. In 2007, Flatberg et al. [18] propose a scenario-based approach with local search. In 2011, Lei et al. [19] propose a two-stage dynamic programming model with recourse, where the recourse consists in going back to the depot as soon as the end of the depot time window is reached. To solve the VRPTW with stochastic travel and service times, Wang et al. [20] present assignment models whereas Li et al. [21] propose a tabu search algorithm. In 2007, Zeimpekis et al. [22] add to this problem priorities within customers (depending on profit, on time window and on travel cost to access a customer) but limit the problem to a single vehicle. For this variant, they propose a variant of the *S*-algorithm [23].

In this paper, we address a different problem as we consider a variant of the VRPTW with multiple depots, priority within customers and stochastic travel and service times. All of these characteristics have not been considered all together previously in the literature. We assume that all customers are known a priori, as well as the minimal, modal and maximal values for speed and service times. Regarding the number of mandatory customers, we suppose that it is sufficient, in order for our method to be consistent. This assumption is not restrictive since, if we do not have enough mandatory customers, we can decide to make some optional customers become mandatory. Making these assumptions, we propose a two-stage method: a planning stage followed by an execution stage. As Delage et al. [8], we decompose the planning stage into two phases: (i) we build routes considering only mandatory customers (we call the set of these routes "skeleton"); (ii) we insert optional customers in this skeleton. At the beginning of the execution stage, we have a planned route for each vehicle. In this stage, we use dynamic programming to deal with the stochasticity on travel and service times. The key idea in this two-stage method is to use the optional customers as buffer to absorb variations on travel and service times. The remainder of the paper is organized as follows. We present the planning stage in Section 2, the execution stage in Section 3, computational results of the two-stage method in Section 4 and we conclude in Section 5.

2. Planning stage

In the planning stage, we aim at building optimal routes containing both mandatory and optional customers. Assuming that lower and upper bounds on travel and service times are known (as mentioned before), we proceed in two phases: first, we build a skeleton of routes serving mandatory customers and then we insert optional customers in this skeleton. In phase I (skeleton design), we formulate the problem as a mixed integer program and we solve it exactly using a commercial solver. In the second phase (insertion of optional customers), we formulate the problem as an integer program and we proceed in two steps: we first solve this model with pessimistic estimates using a branch and cut algorithm or a Lagrangian decomposition method and we then repair and improve the solution with a heuristic method.

2.1. Phase I: skeleton design

In this step, we consider only mandatory customers, which are a priori known and have an associated time window. In order to design the skeleton of routes including mandatory customers only, we just have to solve a m-TSPTW on mandatory customers. As we do not allow any delay for serving mandatory customers, we consider that travel and service times are maximal. Let K be the set of vehicles and M the set of mandatory customers. We note o^k and d^k the origin and destination depots for vehicle k and $[e_i, l_i]$ the time window for customer i (service should begin after e_i and before l_i). Let $\underline{\sigma}_i$ and $\overline{\sigma}_i$ be respectively the minimal and maximal service time for customer i, $\underline{\tau}_{ij}$ and $\overline{\tau}_{ij}$ be respectively the minimal and maximal travel time between i and j. Let T be a large constant. We define the following variables. A binary variable x_i^k indicates if mandatory customer i is served by vehicle k. A binary variable y_{ij}^k indicates if customer i is served just before j by vehicle k, and last t_i corresponds to the time at which service starts at customer i. Then the skeleton design is modelled as follows:

Model 1 (M1):

$$\min \sum_{k \in K} \sum_{i \in M \cup \{o^k\}} \sum_{j \in M \cup \{d^k\}} \overline{\tau}_{ij} y_{ij}^k$$